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DEVELOPMENT OF IDEA PRODUCT FOR GOES-R AEROSOL DATA

The NOAA GOES-R Advanced Baseline Imager (ABI) will have nearly the same capabilities as NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) to generate multi-wavelength retrievals of aerosol optical depth (AOD) with high temporal and spatial resolution, which can be used as a surrogate of surface particulate measurements such as $PM_{2.5}$ (particulate matter with diameter less than 2.5 μm). To prepare for the launch of GOES-R and its application in the air quality forecasting, we have transferred and enhanced the Infusing satellite Data into Environmental Applications (IDEA) product from University of Wisconsin to NOAA NESDIS. IDEA was created through a NASA/EPA/NOAA cooperative effort. The enhanced IDEA product provides near-real-time imagery of AOD derived from multiple satellite sensors including MODIS Terra, MODIS Aqua, GOES EAST and GOES WEST imager. Air quality forecast guidance is produced through a trajectory model initiated at locations with high AOD retrievals and/or high aerosol index (AI) from OMI (Ozone Monitoring Instrument). The product is currently running at http://www.star.nesdis.noaa.gov/smcd/spb/aq/. The IDEA system will be tested using the GOES-R ABI proxy dataset, and will be ready to operate with GOES-R aerosol data when GOES-R is launched.

Development of IDEA Product for GOES-R Aerosol Data

1. Introduction

Elevated concentrations of particulate matter with diameter smaller than 2.5 μm ($PM_{2.5}$) has been found to be harmful to the human health, and can cause diseases such as decreased lung function, respiratory or cardiovascular exacerbation, even premature death from cardiopulmonary causes and cancer [1,2]. The US Environmental Protection Agency (EPA) has been monitoring $PM_{2.5}$ as a criteria air pollutant with over five hundred hourly and over one thousand and eight hundred daily $PM_{2.5}$ surface monitors over the United States.

The surface in-situ measurements can have the problem of gaps between stations: the measurements are not available at the locations between stations. Satellite remote sensing of aerosols has provided a new method for monitoring PM air quality. Satellite derived AOD, which is proportional to the column-integrated concentrations of particulate matter, has been found to be well correlated to the surface $PM_{2.5}$ measurement over the eastern United States [3,4]. This feature makes AOD be used as a surrogate of the $PM_{2.5}$ over the cloud-free regions and periods in which surface measurements are not available.

The Infusing Satellite Data into Environmental Applications (IDEA) product was developed as a tool for air quality forecasters to access satellite AOD images and meteorological parameters in near real-time in order to improve the air quality forecasting ability [3]. It was first developed in 2003 by a team of National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), and EPA researchers. The product was initially run at University of Wisconsin, and it has been migrated to an operational environment at NOAA (http://www.star.nesdis.noaa.gov/smcd/spb/aq/) since 2007. The original product uses AOD data from MODIS Terra (10:30 am local time) such that AOD national and regional maps as well as the trajectory forecasting for the next two days are available to the user in near real-time. In addition, it also provided three-day composite animation of MODIS AOD, $PM_{2.5}$, meteorological data, and fire locations, timeseries plots of MODIS AOD and $PM_{2.5}$ for each individual hourly $PM_{2.5}$ site over a 60-day period, and a national correlation map between MODIS AOD and $PM_{2.5}$. Within the past two years, we have enhanced the IDEA product by including the AOD data from MODIS Aqua (1:30 pm local time), and the AOD data from GOES Aerosol and Smoke Product (GASP) as separate panels. Derived from the geostationary satellite instruments, the GASP can provide AOD at much higher temporal resolution (every 30 minutes) than MODIS over the United States.

The enhanced IDEA product is prepared for the incorporation of GOES-R ABI aerosol product (to be available ~2015), which will have improved spatial, temporal, spectral and radiometric resolution compared to the current GOES satellites. The increased number of spectral bands and increased precision of measurements enable it to have nearly the same capabilities as MODIS to generate multi-wavelength retrievals of AOD with high temporal and spatial resolution. In this paper, we introduce the enhanced IDEA product using the multiple satellite aerosol data and our future research and development to improve the product.

2. Data sources

The data currently used in the IDEA product include aerosol products from satellite instruments MODIS, GOES and OMI, the hourly surface $PM_{2.5}$ measurements from AIRNOW, meteorological forecast data and analysis data from NCEP, and wildfire location data from NOAA.

The satellite aerosol data from MODIS, GOES and OMI are acquired from a NOAA FTP server in near real-time. The MODIS near real-time aerosol product MOD04, and L1B product have a latency of about two and a half hours from the pass of the satellite due to the transmission and processing of data. The MODIS can cover the continental United States with three overpasses in about three and a half hours. The MODIS AOD compares well to surface AERONET measurements [5] and has been shown to be suitable for air quality

monitoring over the eastern part of the continental United States [e.g. 3,4,6]. The GASP [7,8] EAST AOD data covers the continental United States, while the GASP WEST AOD data covers the western part of the continental United States. Both of them are updated every half hour during the sun-lit part of the day. The OMI is on board the EOS-Aura satellite, which is part of A-train and passes the equator at ~1:38 pm, eight minutes behind Aqua [9].

Although there are several aerosol products available from OMI, we use aerosol index (AI) in IDEA, which is derived from measurements at two UV wavelengths (354 nm and 388 nm) [10]. The AI product is sensitive to the aerosol height--- larger AI is associated with UV absorbing aerosols located at high level, and it can also retrieve AI over cloud where AOD cannot be retrieved [11].

Hourly in-situ $PM_{2.5}$ mass concentration data are obtained from the EPA through the AIRNow data management center for over six hundred continuous monitoring sites operated by state and local air monitoring stations, national ambient monitoring stations, and Canadian provinces. Meteorological analyses and forecast data with 3-hr interval generated by the NOAA/NCEP WRF model are obtained from NOAA/ Oceanic and Atmospheric Research (OAR)/Air Resources Lab (ARL) (analysis data) and NOAA/NCEP (forecast data). The fire burn locations at half-hourly temporal resolution generated by the WildFire Automated Biomass Burning Algorithm (WF_ABBA) from GOES-12 observations are obtained from NOAA/NESDIS.

3. Product components

The IDEA product is displayed through a website located on NOAA's web server. The product components include national and regional imagery of AOD from multiple satellite instruments, 48-hour trajectory forecasting, three-day composite animation of AOD, surface $PM_{2.5}$ measurements, wildfire locations, and meteorological fields, and analysis of the coincidence of surface measurements and AOD, including timeseries, scatter plots, histograms of $PM_{2.5}$ and AOD, and national correlation map between $PM_{2.5}$ and AOD.

National and regional AOD images from the MODIS Terra, Aqua, GOES EAST and GOES WEST are plotted as soon as new satellite data are received (Figure 1). Regional AOD images are plotted for ten EPA-defined regions with region 1-3 combined and region 4-10 shown as individual maps. For the national map from MODIS, true color images are also plotted using L1B data, on which AOD map is overlaid. Users can use a slider to choose the weight between AOD images and true color images in areas with AOD retrievals. The GASP channel 1 reflectance is plotted in areas covered by clouds. The GASP AOD regional and national images are also made into animations for each day so that users can view the movements of aerosols.

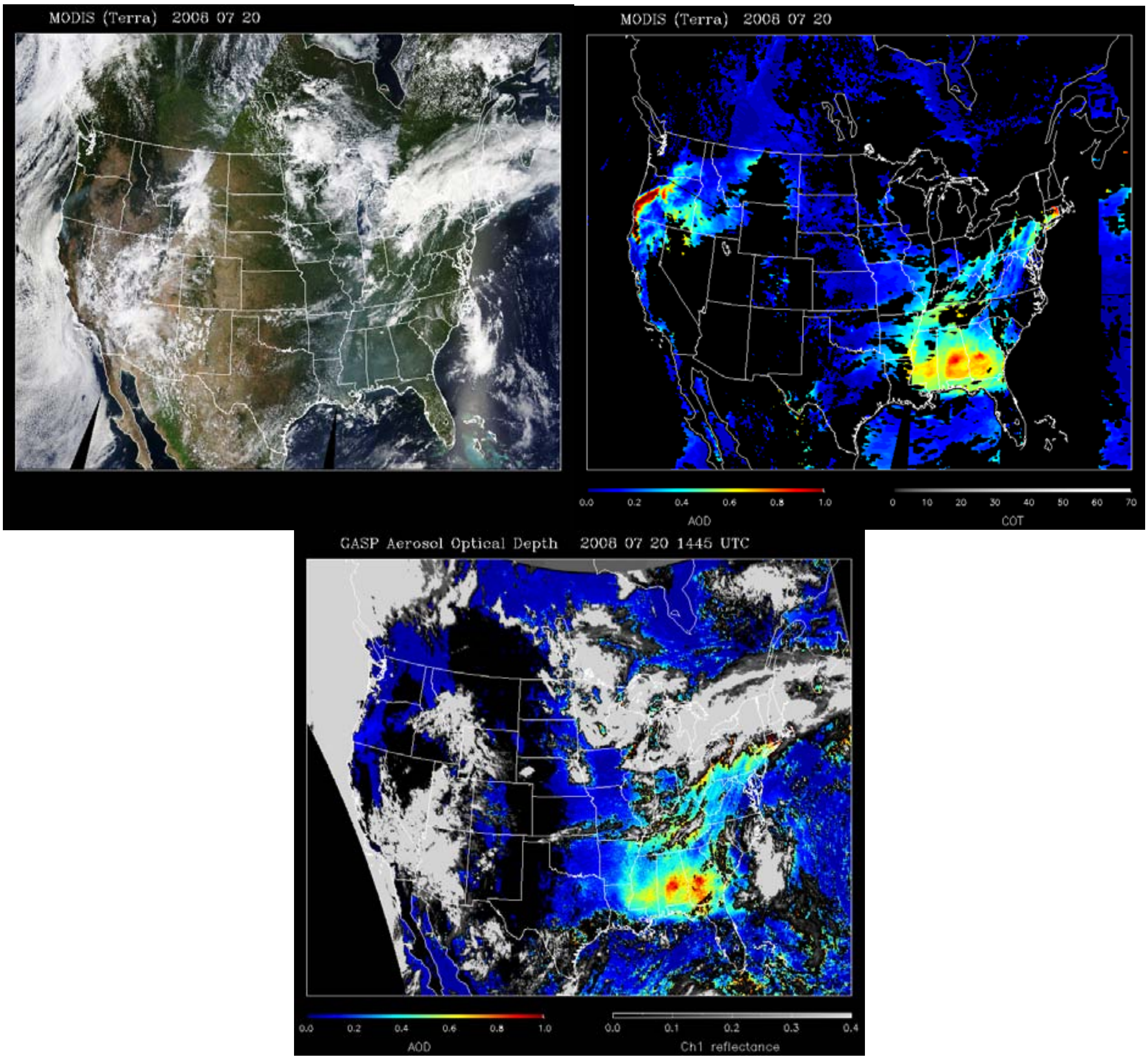

Figure 1. Examples of national image of true color plot (top left) and AOD plot (top right) from MODIS, and national image of AOD & channel 1 reflectance from GOES-12 (bottom).

48-hour trajectories are initiated from the areas with high AOD and/or AI. With the addition of MODIS Aqua and GASP data, more trajectories are initiated than the previous product. The foreward trajectories are initiated twice per day from MODIS AOD, three times from GASP east AOD, and twice from GASP west AOD. The trajectories of air parcels are calculated starting from the locations where AOD is higher than 0.4 at four levels above surface with 50mb increment (e.g. 950, 900, 850, and 800mb if surface pressure is 1000 mb), since aerosols are usually located close to the surface within the planetary boundary layer (PBL). For the forecasts from Aqua AOD, OMI AI [10] is incorporated to locate aerosols at high levels. Since high OMI AI represents high aerosol load at high level and it is taken eight minutes after Aqua AOD, the initialization levels of the air parcels are defined at 300mb above surface levels (about 3km above surface) for those locations with AI larger than 2.0, instead of the four levels close to the surface. Following are the possible OMI AI and Aqua AOD combinations: (1) high AI, high AOD, (2) high AI, no AOD, (3) high AI, low AOD, (4) low AI, high AOD, (5) no AI, high AOD. For cases (1),(2), and (3), the trajectories are initialized at 300mb above surface. For cases (4) and (5), the trajectories are initialized at four levels close to the surface. The 48-hour trajectories of these air parcels are shown in an animation together with the AOD image, 850 mb wind field, and precipitation field (Figure 2). This product can be used as a guidance for the air quality forecasters to determine the movements of the poor air quality. A verification page of national AOD image is available after two days of each forecast so that users can compare the projected aerosol tracks with the reality.

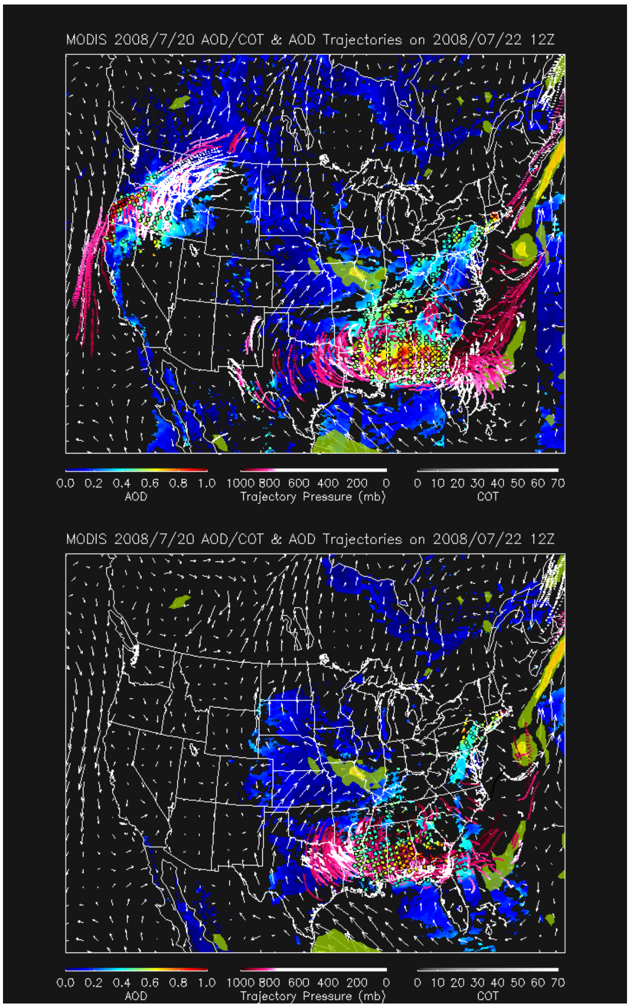

Figure 2. A frame from 48-hour forward trajectory initiated from Terra AOD (top) and Aqua AOD (bottom).

Three-day animation of composite images of AOD, $PM_{2.5}$, fire locations and 850-mb winds show the simultaneous variations of these variables (Figure 3). By looking at such animations, users can have a synoptic view of the movement of the pollutants both from the space and the surface, and their relations with the wind and fire locations. The surface measurements are usually qualitative in agreement with the AOD from satellite measurement.

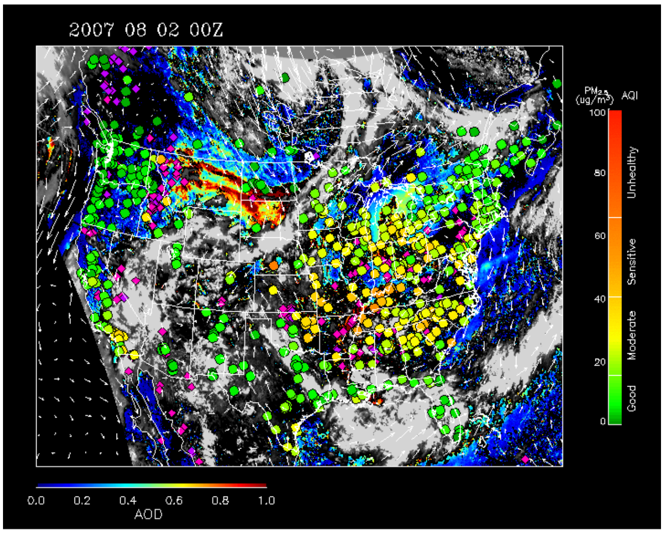

Figure 3. A frame from three-day animations of composite image of GASP AOD, channel 1 reflectance, $PM_{2.5}$, fire locations, and 850mb wind.

For each hourly $PM_{2.5}$ station, a timeseries plot is generated every day for the past sixty days including the AOD from MODIS, GASP and surface measurements of $PM_{2.5}$ (Figure 4 top left). Scatter plots (Figure 4 top right) and histograms (Figure 4 bottom) of the matchups between AOD and $PM_{2.5}$ are also shown for each site during the past 60 days. With these plots, users can see the history of air quality and how well the surface $PM_{2.5}$ can be represented by the satellite AOD for each site during the past 60 days. The EPA classification of air quality based on $PM_{2.5}$ is plotted on the left side of the timeseries for reference, where the air quality is defined as good (0-15.4 $\mu g\ m^{-3}$), moderate (15.5-40.4 $\mu g\ m^{-3}$), unhealthy for sensitive groups (40.5-65.4 $\mu g\ m^{-3}$), unhealthy (65.5-150.4 $\mu g\ m^{-3}$), and very unhealthy (150.5-250.4 $\mu g\ m^{-3}$).

National correlation maps are produced every day for the correlations between MODIS AOD and $PM_{2.5}$ and GASP AOD and $PM_{2.5}$ over the hourly $PM_{2.5}$ sites for the past 60 days (Figure 5). These plots provide a synoptic view of how well the AOD can represent surface $PM_{2.5}$ in different regions.

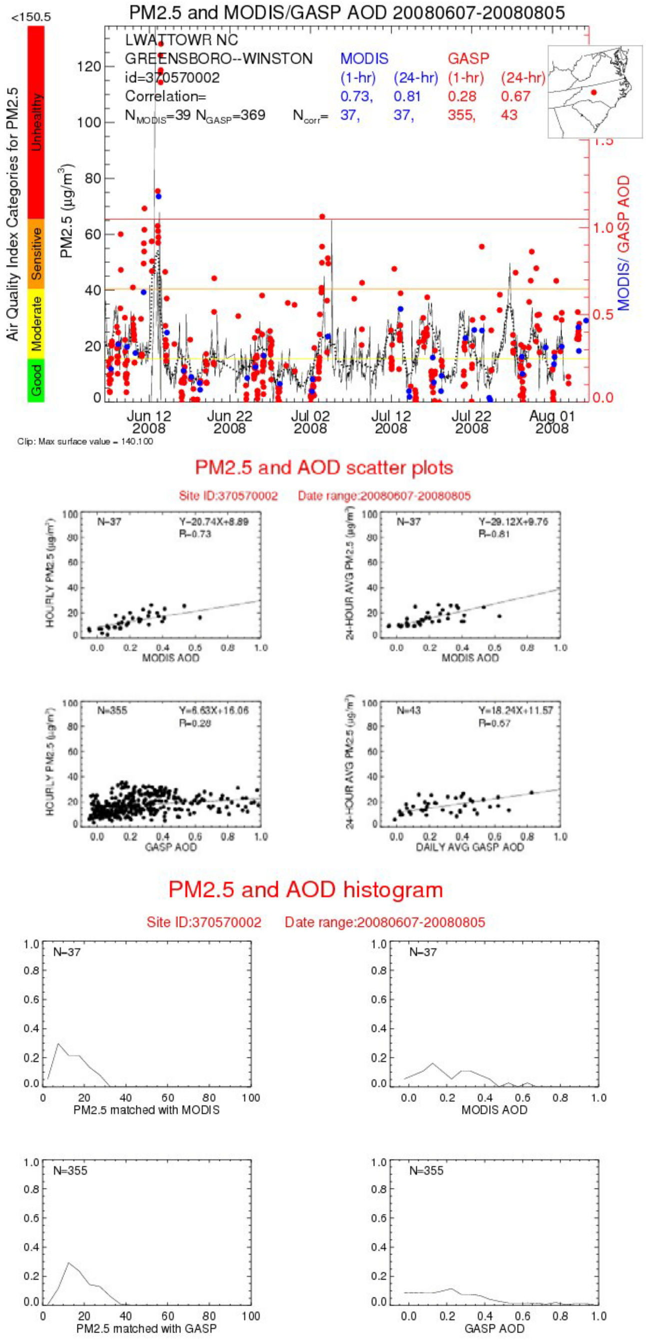

Figure 4. An example of the plots of timeseries, scatter plots, and histograms for an hourly $PM_{2.5}$ site.

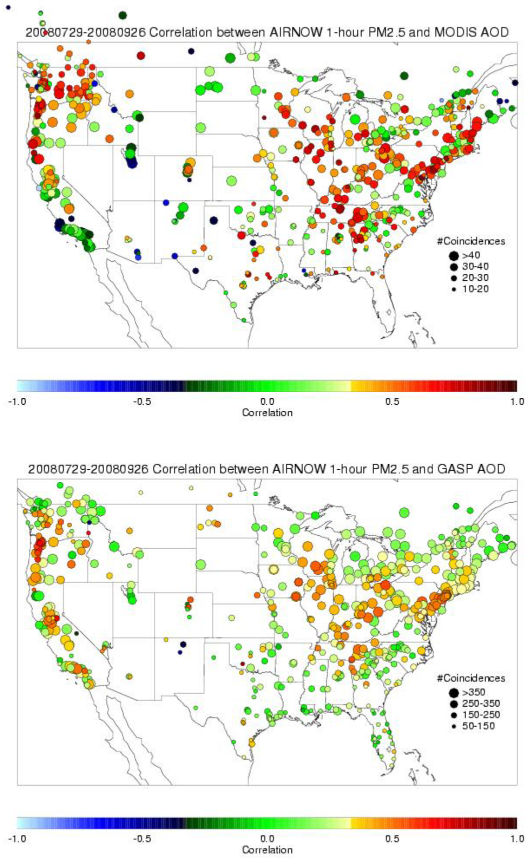

Figure 5. National correlation maps between AOD and $PM_{2.5}$, the left is for MODIS, the right is for GASP EAST.

In addition, satellite AOD datasets are produced daily into formats that are easily used by air quality researchers. One of these is the matchup dataset of AOD to the more than 1800 daily EPA $PM_{2.5}$ monitoring sites. This dataset is available through EPA AIRQuest decision support tool through a web service [12]. The other is the regridding of the AOD data onto the 12 km resolution CMAQ (Community Multiscale Air Quality system) grid current used in the NCEP air quality modeling [13]. This dataset is expected to be placed into the Remote Sensing Information Gateway (RSIG) [14] and is currently available from the lead author.

4. $PM_{2.5}$ estimation from AOD

The relation between AOD and $PM_{2.5}$ has been found to vary seasonally and regionally over the United States. In general, the correlation between AOD and PM2.5 are higher in the eastern U.S. than those in the western U.S. The correlations are usually higher in the summer and in the fall than in the winter and in the spring [15]. GASP AOD has high temporal resolution, but it is less accurate than the AOD retrievals from MODIS. The reasons are (1) GASP AOD retrieval uses only one channel for retrieval of both AOD and surface reflectance; (2) GOES imager does not have onboard calibration; and (3) a single predefined aerosol model are used for look-up-table (LUT) generation [8]. In comparison, MODIS uses multi-channels to achieve the AOD and surface reflectance retrieval. This makes GASP AOD less correlated with surface $PM_{2.5.}$ It can be seen in Figure 5 that the correlation coefficients between GASP AOD and $PM_{2.5}$ are lower than those between MODIS AOD and $PM_{2.5}$ in most of the regions.

There have been many research works performed in relating AOD and $PM_{2.5}$, including simple linear regression [4,15], multivariate regression [16,17], and more complicated methods such as using chemical transport model results to include vertical profile of the aerosol layers [18], etc. In IDEA product, a fixed ratio of 1:62 between AOD and $PM_{2.5}$ is assumed in plotting 60-day timeseries graphs of AOD and $PM_{2.5}$ for each hourly $PM_{2.5}$ station. In a recent study, we investigated linear regression relations between MODIS AOD and $PM_{2.5}$ over the ten EPA-defined regions and calculated the slopes and intercepts for each region and season. We found using these regression relations to estimate the surface $PM_{2.5}$ can be more accurate than the simple AOD-PM2.5 ratio of 1:62 used in current IDEA product [15]. A review of the literature on such measurements has been recently published [6]. We are currently working on incorporating more seasonally and spatially specific relationships into IDEA.

The MODIS aerosol product experienced major version change during the transition of IDEA product. In the original IDEA product in the University of Wisconsin, MODIS aerosol product collection 4 was used. After the transition, MODIS aerosol product has been changed to collection 5. The MODIS collection 5 aerosol product uses modified assumptions in the surface reflectance retrieval algorithm over land, and it also utilizes a more stringent cloud masking algorithm. This new cloud masking algorithm removes more cloud contaminated AOD pixels than the one in collection 4 product, and increases the correlations between AOD and $PM_{2.5}$ compared to those between collection 4 AOD and $PM_{2.5}$. However, due to this cloud masking algorithm, the areas of AOD retrievals are also smaller, which results in a 20-30% reduction in the number of coincidences of AOD and $PM_{2.5}$ compared to those of the collection 4 AOD and $PM_{2.5}$ [15].

5. Future Developments

We are currently working on investigating and developing new components and preparing the IDEA for the GOES-R data. These include developing air quality index map based on the satellite AOD, developing an "aerosol wind" product which derives the aerosol movements from consecutive GOES AOD retrievals, and simulation of the IDEA system using GOES-R proxy data.

Although $PM_{2.5}$ can be estimated from AOD retrievals, the accuracy is still low. Gupta showed that it is more accurate to estimate the EPA-defined air quality levels (green 0-15.4, yellow 15.5-40.4, etc, as described in last section) than estimate the $PM_{2.5}$ values. In this way, the air quality levels can be estimated to be accurate 98% of time [19]. Based on these research works, we will develop a national air quality level map product using the estimation of $PM_{2.5}$ from AOD. The estimation of $PM_{2.5}$ will be performed using the seasonal and regional varying regression relations.

Since GOES-R ABI aerosol retrieval will provide high temporal frequency with update of every 15 minutes during sun-lit time, the movement of the aerosol (aerosol wind) can be derived from correlation analysis from consecutive images. Before the launch of GOES-R, we will use the half-hourly GASP AOD product as input. This aerosol wind field can be further used to correlate with the wind profile to derive the locations of vertical levels of aerosols.

As ABI proxy datasets become available, development of compatible GOES-R AOD inputs will be necessary to ensure continuity of the IDEA product. It is unlikely the format of GOES-R AOD will match either MODIS or GASP and a reader will need to be built for GOES-R IDEA. We will work with the developers of the GOES-R AOD algorithm to ensure the interface to this higher-level product is achieved. In addition to AOD, the ABI will also produce aerosol type information, such as dust, smoke, or industrial pollutant. This information will also be presented in the future IDEA system.

6. Conclusions

We have successfully transferred the IDEA product from University of Wisconsin to NOAA/NESDIS and made it run in near real-time. The original MODIS Terra based product was enhanced by introducing new satellite aerosol product from MODIS Aqua, GASP EAST, GASP WEST, and OMI. Several new components will be developed for the future IDEA product. The relation between AOD and $PM_{2.5}$ will be refined for different regions and seasons, and will be applied in the new IDEA components for generation of air quality level map. The system will be made compatible to the GOES-R aerosol product when the proxy datasets are available.

7. Acknowledgements

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